International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 9, Issue 2, Apr 2019, 439-448

Original Article

CFD ANALYSIS OF CRYOGENIC HELICAL COILED SHELL AND TUBE HEAT EXCHANGER

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ABSTRACT

Present study deals with the CFD (computational fluid dynamics) analysis of helical coil - shell and tube counter flow heat exchanger, which is used in cryogenic applications owing its compact construction and larger heat transfer area. The counter flow analysis is carried with two different fluids, namely gaseous hydrogen and liquid nitrogen, respectively. The analysis was carried out in ANSYS FLUENT 15.0 to get the static temperature, pressure, and velocity. Copper was chosen as a fabrication material for both shell and tube. The results revealed that for a given geometry of heat exchanger, an improvement in heat transfer and decrease in velocity were observed. Hence, the heat transfer and fluid flow analysis are essential for helical coil heat exchangers to get enhanced and extra quantitative approach.

KEYWORDS: Heat Exchanger, Helical Coil, Temperature, Counters Flow & Velocity

Received: Jan 17, 2019; **Accepted:** Feb 07, 2019; **Published:** Mar 07, 2019; **Paper Id.:** IJMPERDAPR201943

1. INTRODUCTION

Shell and tube (or) Tube in tube heat exchanger plays key role in the improvement of heat transfer rates when operating with different heat transfer fluids. The flow of fluid could be parallel or counter flow type of configuration is used in heat exchanger. In helical coil heat exchangers, the secondary flow exists normal to the primary flow axially, and hence the heat transfer rate is enhanced. Further, it puts forward additional heat transfer area surrounded by little space and thus higher overall heat transfer coefficients stay alive. The boundary conditions used in the application of heat exchanger design are constant heat flux and constant wall temperature. However, the helical coils have drawbacks with these boundary conditions. Different studies have suggested using the constant heat flux, and constant wall temperature boundary conditions were preferred because of deficient experimental data accessible, concerning the action of the fluid flow in coil heat exchangers. Thus, *CFD* analysis is the suitable approach to determine the heat transfer description for tube in tube helical coil heat exchanger and for fluid flow pattern. Pramod *et al.* [1] conducted CFD analysis of heat transfer in helical coil shell and tube heat exchanger and the variations in temperature were plotted using ANSYS Fluent 15.0. The fabrication metal for both the shell and the tube used was copper and the working fluid is water. Saikhedkar *et al.* [2]compared the experimental and CFD results using ANSYS CFX, and they conducted a study to determine the effects of heat transfer analysis of helical coil heat exchanger by considering the parameters like pitch length of helical coil and mass flow rate of fluids. Further, it was clinched that the CFD analysis results equitably match with the experimental outcomes. Amit *et al.* [3] designed the helical coil shell and tube heat exchanger and thermally evaluated using counter-flow arrangement. In addition, thermal analysis was carried out by considering different operating parameters such as overall heat transfer coefficient, cold and hot water flow rates, effectiveness, and

temperature. Gimadiev *et al.* [4] studied about coil heat exchanger with counter flow configuration with 30 experiments and developed a semi-empirical correlation to determine the overall heat transfer. Further, transient temperature response was analysed theoretically and experimentally, when the inlet temperature experiences sudden change and the active behaviour was approached periodically with a time delay link. Stutz *et al.* [5] proposed a 3D finite element model of helical coil Ground heat exchanger (GHE), emphasizing on actual geometry energy mined from the earth's crust, and the results conclude that an intermittent short time operating mode enhances the GHEs performance. Further, the3D finite element model would be supportive in studying helical coil GHE's difficulties apart from the basic assumptions of typical 2D axis-symmetric models. Rahman *et al.* [6] presented the used different Nano-fluids such as CuO-H_2O, Al_2O_3-H_2O, and ZnO-H_2O) in coil heat exchanger and the analytical investigation was performed at entropy generation rate and convective heat transfer coefficient at different nanofluid volume fractions and volume flow rates. Among all the test fluids used, theCuO-H_2O has shown better characteristics. In addition, heat transfer coefficient was better with increase in volume flow rate and volume concentration, while the generation of entropy was reduced. Ashish *et al.* [7] presented the heat transfer investigation of straight helical coil and conical coil heat exchanger with different fluid flow rates and curvature ratio. Additionally, for a range of mass flow rates and temperature, difference was observed along the heat exchanger. They revealed that the effectiveness of heat exchanger reduced with higher dean number. Also, it was seen that, the heat transfer coefficient is greater for helical coil compared to conical and spiral coil heat exchanger.

2. DESIGN METHODOLOGY

The shell and tube helical coil heat exchanger was modelled and analysed using CFD in ANSYS WORKBENCH 15.0 design module. The following steps are taken for the analysis.

2.1. Geometry

The following steps were followed to model a coil heat exchanger.

2.2. Sketching

The sketching was selected in three dissimilar planes such as XY, YZ, and ZX planes. The line of 50 mm height of helical structure was drawn and a new plane was formed in position to YZ-plane. The new sketchers were added with respect to this plane. Further, 14 mm circle was drawn with a distance of 50 mm from the origin. Likewise, two more circles were drawn with diameters of 14 mm and 16 mm by making concentric to preceding circle. Yet again two circles with 16 mm and 20 mm diameters were made concentric to prior circles. The same procedure was followed for the 20 mm and 22mm diameter circles were made concentric with past circles. These circle were all together swept all along the line in original sketch, by using the operation "add frozen" for making a complete 3D model with dissimilar parts. After the sweep operation, the model was shown its different parts. These parts were merged using merge operation to make all the parts put together. The modelled geometry (heat exchanger) is depicted in Figure 1.

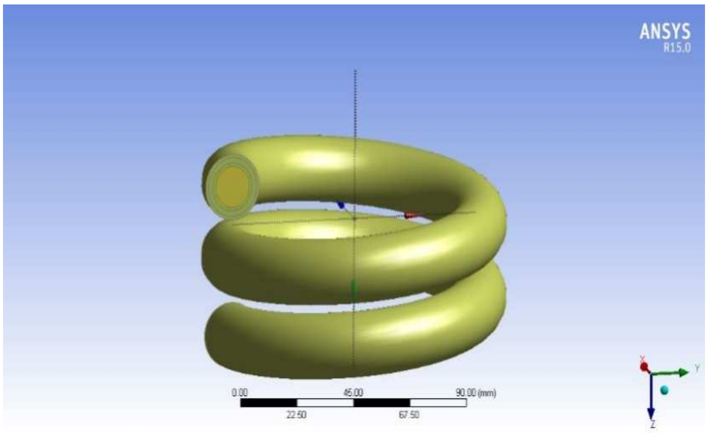

Figure 1: Pictorial View of Original Geometry

2.3. Meshing

The modelled geometry was allowed for meshing. In this analysis, both coarse and fine mesh is used on account of mixed cells. Initially the coarse mesh with tetrahedral cells is used to lessen numerical diffusion structuring the mesh in a fine approach close to the wall area. The pictorial view of meshed geometry is shown in Figure 2, and the Table 2 represents the mesh details. The naming at each section is given in Table 2, and its pictorial view is depicted in Figure 3. Finally, the mesh quality is checked.

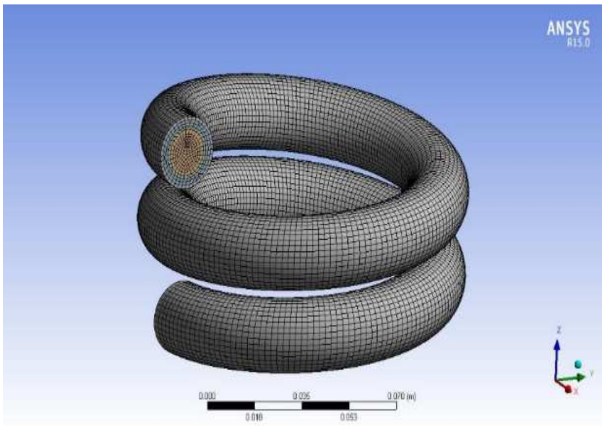

Figure 2: Pictorial View of a Mesh

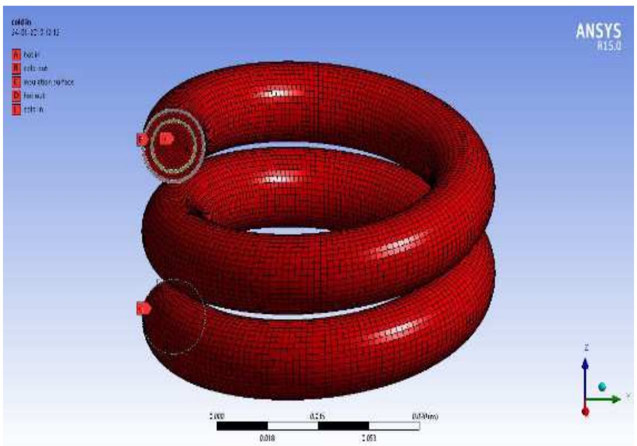

Figure 3: Pictorial View of Named Selections

Table 1: Mesh Details

Constraints	Value
Advanced Size Function	Curvature
Mesh type	Coarse
Smoothing	Medium
Changeover rate	Slow
Curvature angle	12.0°
Minimum size	0.000058423m
Maximum size	0.011685m
Maximum Face Size	0.0058423m
Nodes	109782
Elements	103323
Mesh Metric: a) Skewness b) Orthogonal Quality	 Average - 0.220 Average - 0.921

Table 2: Named Selections

S.No	Part	Phase	Fluid
1	Hot fluid	Gas	Hydrogen
2	Cold fluid pipe	Solid	Copper
3	Cold fluid	Liquid	Nitrogen
4	Hot fluid pipe	Solid	Copper
5	Insulation Surface	Solid	Copper

2.4. Solution Setup

The inlet temperature of gaseous hydrogen is 300K and the inlet temperature of the liquid nitrogen is 77K. The pressure based analysis is used as outlet parameter and the velocity values are given as inlet parameter with steady state condition. Acceleration due to gravity is -9.81 m/s^2.

Models

Energy option was activated and the “k-ε model (2nd equation) was chosen as viscous model.

Radiation was off.

Materials

The fluids are chosen as gaseous hydrogen-liquid nitrogen and copper was taken from the database list as solid.

Cell Zone Conditions

The parts are assigned as gaseous hydrogen, liquid nitrogen, and Copper as per fluid/solid parts.

Boundary Conditions

Boundary conditions are used according to the need of the model. The velocity and pressure were chosen as inlet and outlet boundary conditions. Also, the walls were specified as no heat flux condition and no slip conditions.

Solution Methods

The following solution methods were used in this analysis as presented in Table 3.

Table 3: Solution Methods

Parameter	Method
Scheme	Simple
Gradient	Least Square Cell Based
Pressure	Standard
Momentum	Second Order Upwind
Turbulent Kinetic Energy	Second Order Upwind
Turbulent Dissipation Rate	Second Order Upwind

Solution Control and Initialization

The solution initialization method is set to standard initialization while the reference frame is positioned to relative cell zone and the solution is initialized.

Measure of Convergence

The number of time steps taken was 300 and the time step size was 1. The maximum iterations per time step are 50. It had a good convergence throughout the simulation.

3. RESULTS AND DISCUSSIONS

3.1. Contours & Path Lines

Figures 4-9 shows the various cantors and path lines of temperature, pressure, and velocity along the heat exchanger length.

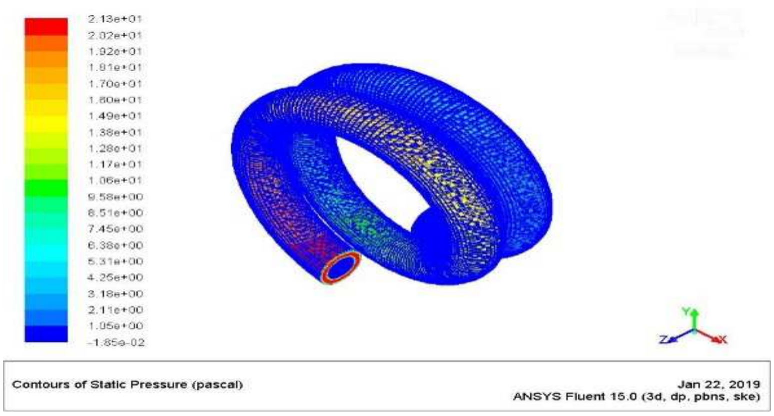

Figure 4: Contours of Static Pressure

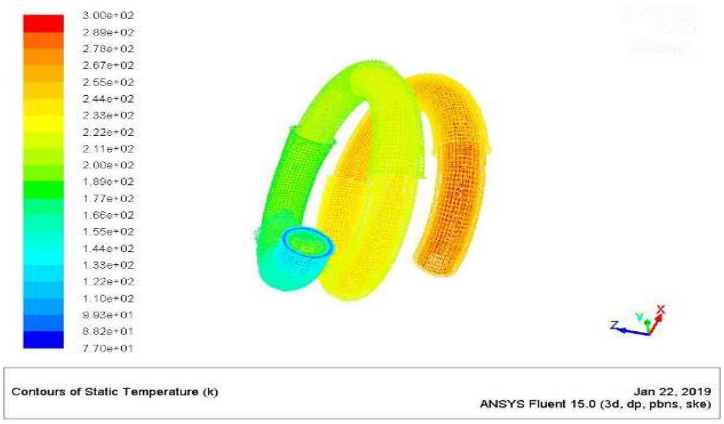

Figure 5: Contours of Static Temperature

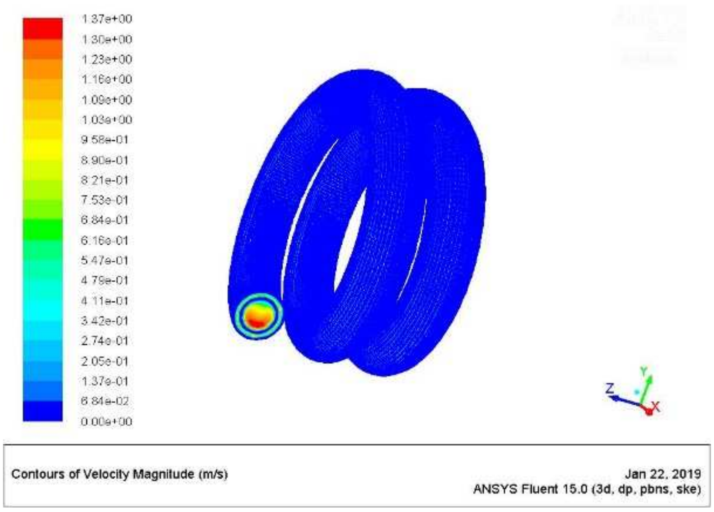

Figure 6: Contours of Velocity Magnitude

Figure 7: Path Lines of Static Temperature

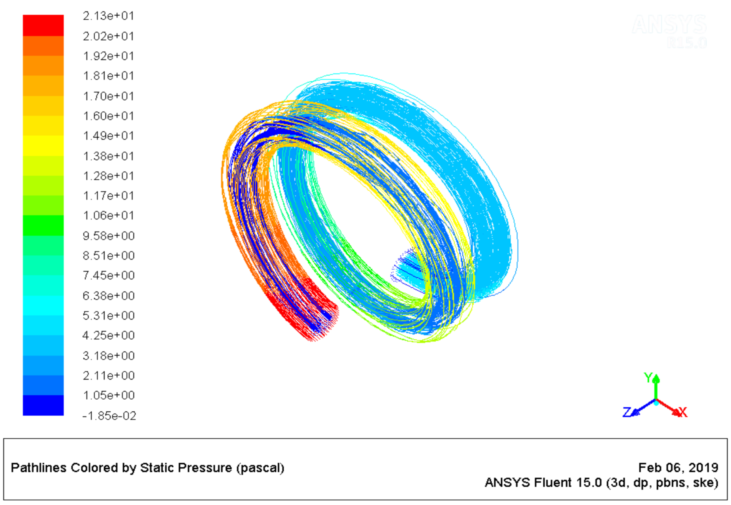

Figure 8: Path Lines of Static Pressure

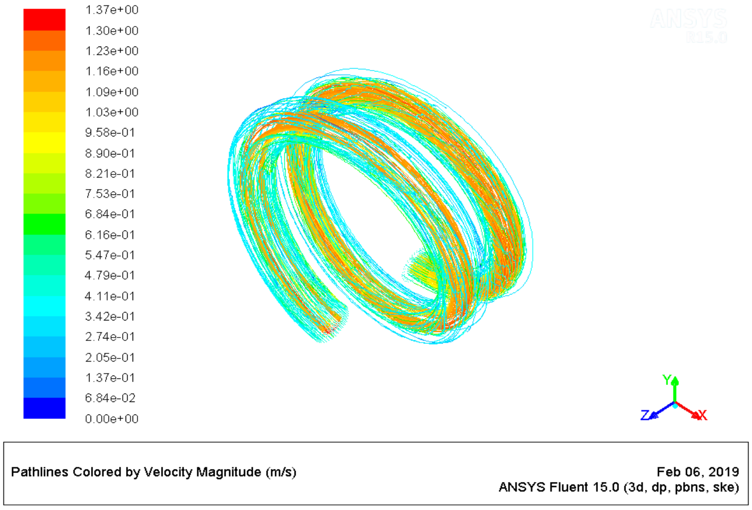

Figure 9: Path Lines of Velocity Magnitude

3.2. X-Y Plots

The X-Y Plots of static temperature and pressure of cold and hot fluids along the heat exchanger can be seen from Figures. 10-13.

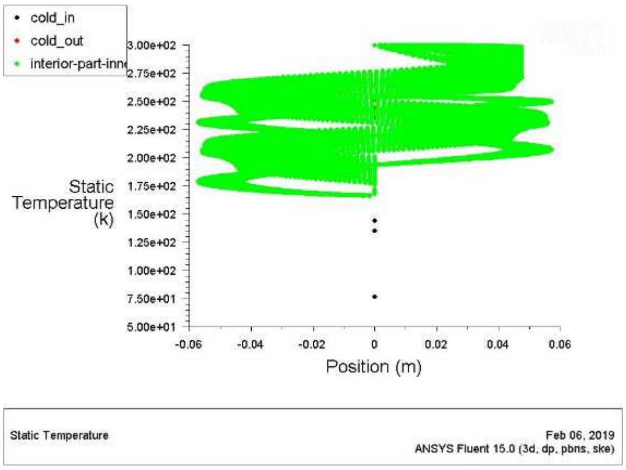

Figure 10: X-Y Plot of Static Temperature of Cold Fluid Inlet and Outlet

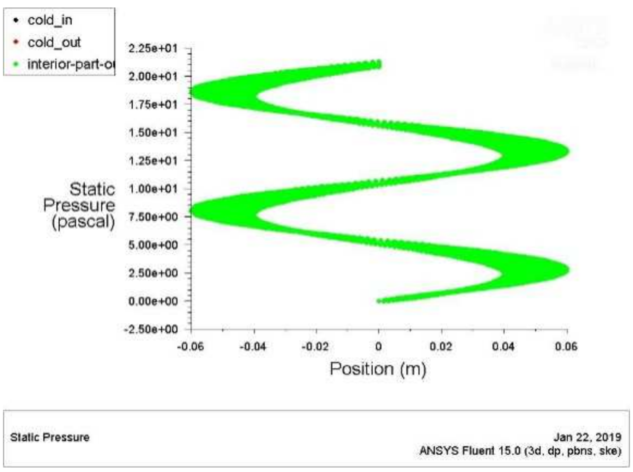

Figure 11: X-Y Plot of Static Pressure of Cold Fluid Inlet and Outlet

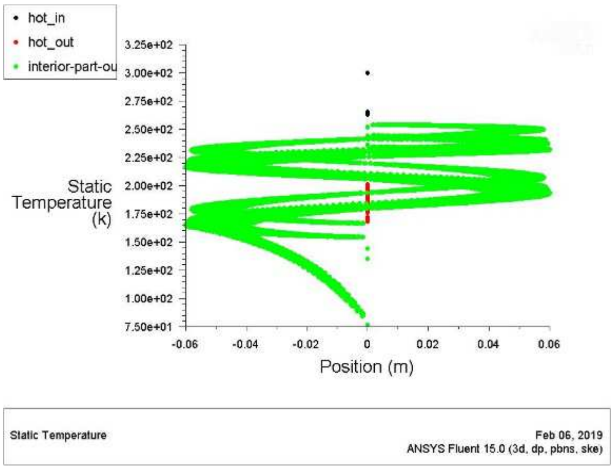

Figure 12: X-Y Plot of Static Temperature of Hot Fluid Inlet and Outlet

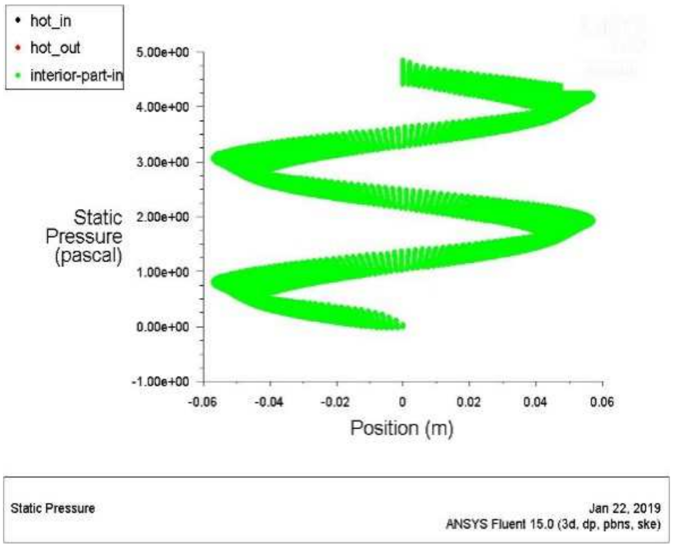

Figure 13: X-Y Plot of Static Pressure of Hot Fluid Inlet and Outlet

4. CONCLUSIONS

The following conclusions were arrived from this study.

- The CFD analysis suits for the heat exchanger applications.
- Better heat transfer was observed with the two fluids. It can be observed that the inlet temperature of the gaseous hydrogen was dropped from 300K to 246 K while the liquid nitrogen temperature increased from 77K to 134 K. Hence, the heat transfer is perfect with the geometry used in this study and with operating conditions.

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